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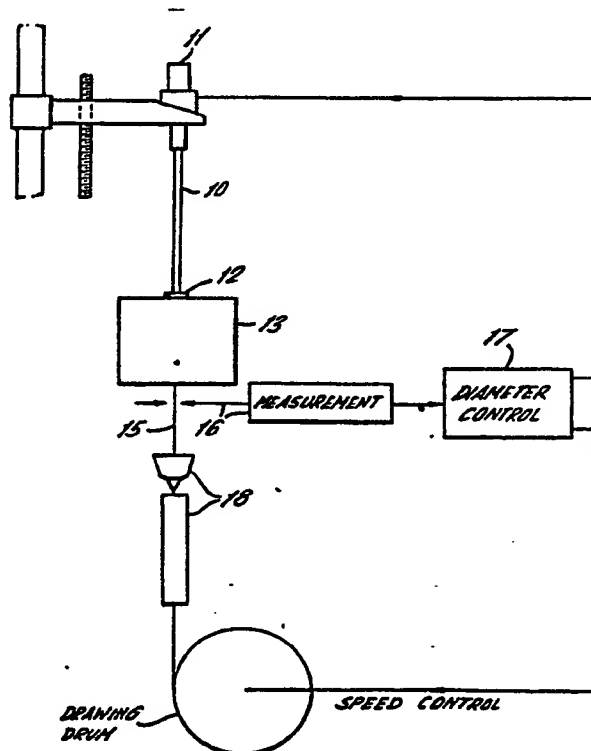


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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**(54) Title:** OPTICAL FIBRES AND THEIR MANUFACTURE**(57) Abstract**

An optical fibre such as might be used for the transmission of data or as a sensor, is formed of substantially torsion-free material which is twisted during drawing to have a rate of twist per unit length greater than the intrinsic birefringence. The material is torsion-free hence avoiding the torsional stresses which produce circular birefringence but the spinning averages out the stress induced linear birefringence and the form birefringence. The spinning thus ensures that residual polarisation mode dispersion is reduced to a negligible value. Figure 1 illustrates one technique for making such fibres, a preform (10) fed into a drawing furnace (13) is spun by a motor (11) to impart the required twist to the fibre (15).



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"OPTICAL FIBRES AND THEIR MANUFACTURE"

This invention relates to optical fibres and their manufacture.

5           Optical fibres find particular application for the transmission of data and also as sensors. The present invention is concerned with fibres for both these applications.

10           Considering firstly fibres used as sensors, such devices rely for their operation on modification of the optical wave guide parameters by external means such as pressure or tension or external fields such as magnetic or electrical or acoustic fields. Single mode fibres are of particular interest for this purpose  
15           since they ideally have a single, well defined phase velocity and hence polarisation state. It becomes possible therefore to observe small variations in polarisation. Theoretically, a circularly-symmetric, stress-free,



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straight fibre would be suitable but in practice fibres have a degree of ellipticity which is accompanied by an associated stress asymmetry. The fibre then supports two orthogonally polarised modes with differing phase velocities. The fibre thus appears birefringent and the output state of polarisation will vary cyclically along the fibre length with a period which is dependent on the difference in the propagation constants of the two modes. The length over which one period occurs is known as the polarisation beat length. It is generally found furthermore that the output state of polarisation is not stable with time because of thermal and mode coupling effects which modify the difference in propagation constants and the power distribution between the modes. The birefringence caused by the core ellipticity is known as form birefringence and the birefringence due to the associated stress asymmetry is known as stress birefringence.

It has been proposed to obtain a more stable linearly polarised output by exciting only one polarised mode in a fibre having very high birefringence; such a fibre has been termed "polarisation-maintaining" fibre. For a Faraday effect current transducer however in which the fibre is responsive to an external magnetic field, such an approach is unsuitable since the presence of linear birefringence in the fibre quenches the small



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Faraday rotation once the fibre length exceeds half the polarisation beat length. Thus the interaction length between the fibre and the magnetic field and hence the sensitivity is very small for a "polarisation-maintaining" fibre with its sub-millimetre beat length. It is preferable therefore to use a low birefringence fibre for a Faraday effect current transducer since the polarisation beat length can be several tens of metres. The latter type of sensor may thus be looped around a large current-carrying conductor to form an ammeter.

In communication systems, the presence of two non-degenerate orthogonally polarised fibre modes can similarly be a disadvantage. The presence of two modes in the fibre can lead to a reduction in bandwidth as a result of a difference in their respective group delays (polarisation mode dispersion). This dispersion is particularly significant in long links, for example of 100 kms or more, as are presently envisaged for some purposes.

Consideration in the past has been given to the use of twisted fibres. It may be shown that the intrinsic fibre linear birefringence is considerably reduced when a fibre is highly twisted (once the local birefringence is averaged along the length of the fibre). However the twisting of a fibre after it has been drawn



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introduces torsional stresses which result in the introduction of a substantial circular birefringence due to the photo-elastic effect. An optical fibre might be considered as a stack of birefringent plates. If the

5 fibre is twisted, the principal axes of these plates are rotated relative to one another. However in such an analysis, it is necessary to include a photo-elastic effect to allow for the torsional stress and induced circular birefringence that is developed in a fibre

10 twisted after drawing. Thus one has to consider, using this method of analysis, the fibre as comprising a number of birefringent plates with their principal axes progressively rotated with respect to each other but which are interspersed by optical rotator elements to

15 simulate the photo-elastic effect. An analysis of this nature shows that the state of output polarisation of such a twisted fibre, for a linearly polarised input, will, as one moves along the fibre, oscillate between right and left elliptical polarisation with a simultaneously

20 rotating azimuth. Provided the twist is large relative to the intrinsic fibre linear birefringence, the latter will appear to be quenched, leaving only the twist-induced circular birefringence. In this case, the intrinsic linear birefringence does not affect the sensitivity of

25 the fibre when used as a current monitor. Although a twisted fibre Faraday current monitor has been demonstrated,





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twisting the fibre after drawing is inconvenient and difficult where a large twist is required and results in residual photo-elastic rotation which is temperature-sensitive.

5           In a fibre used for communication purposes, it can be shown that twisting reduces the polarisation mode dispersion caused by the intrinsic linear birefringence. However this is offset by the introduction of additional pulse dispersion arising from the wavelength dependence  
10 of the photo-elastic coefficient. Twisting the fibre thus reduces the bandwidth limitation due to one effect whilst replacing it with another.

          According to one aspect of the present invention, an optical fibre is formed of substantially torsion-free  
15 material with a rate of twist per unit length greater than the intrinsic birefringence. The rate of twist per unit length is preferably at least ten times the intrinsic birefringence.

          Considered from another aspect, a method of making  
20 an optical fibre comprises drawing the fibre from a heated preform whilst effecting continuous relative rotation between the preform and the drawn fibre. Drawing the fibre from a heated preform enables the twisting to be effected whilst keeping the fibre material  
25 substantially unstressed. Such a fibre will be termed hereinafter a "spun" fibre to distinguish it from a twisted



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fibre which, as previously explained, has circular birefringence arising from torsional stress whereas the spun fibre of the present invention has little or no torsional stress and hence circular birefringence.

5           It is important to distinguish between torsional stresses (which produce circular birefringence) and intrinsic stresses. The latter are generally found in the fibre at all times as a result of the expansion coefficient mismatch which occurs between the silica  
10           substrate and coating material.. If this stress is asymmetric (as found in a slightly elliptical fibre), it will produce linear birefringence. As will now be shown, the stress-induced linear birefringence can be averaged out by spinning, just as can the form  
15           birefringence.

          As previously explained, optical fibres in practice are not exactly circular but have an elliptic cross-section. If the fibre is spun during drawing, the azimuth of the asymmetric cross-section precesses along  
20           the length of the fibre. The fibre can be considered as composed of individual local sections with alternating birefringence values. Although each section has a relatively high local birefringence, its effect is compensated by the next rotated birefringent section.  
25           Because of the absence of torsional stress in a spun fibre, as distinct from a twisted fibre, one can consider the



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optical effect as a series of birefringent sections without interspersed rotator sections. The overall effect of a fibre produced in this way is that there is an apparent birefringence which, along the length of the fibre, oscillates between a small positive and a small negative value.

If the rate of twist (which may conveniently be measured in radians per metre) is large compared to the intrinsic form and stress birefringence (which may also be measured in radians per metre) the magnitude of the oscillation becomes negligibly small. Thus the spinning of the preform during drawing greatly reduces the contribution to birefringence due to form and stress asymmetry. Similarly, the time delay between the orthogonal modes caused by polarisation mode dispersion in a conventional unspun fibre is reduced in a spun fibre to a much smaller value, the reduction being by a factor which depends on the spin rate.

Preferably the preform is spun as the fibre is drawn. The spinning is preferably at a rate to give a uniform number of turns per unit length. Conveniently the fibre is drawn at a substantially constant rate and the preform is spun at a substantially constant rate. However it is known in producing optical fibres to control the rate of drawing in order to maintain the fibre diameter constant. In such a technique, the rate



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of spin may be controlled in accordance with the rate of drawing in order to maintain a uniform twist pitch.

It is not necessary, however, for the spin rate to be constant to achieve the desired result. It could  
5 even reverse in direction, e.g. reverse periodically or be random in nature, oscillating from a right-handed to a left-handed twist. Provided the twist rate is, on average, greater than the birefringence, such twisting would reduce the birefringence.

10 The preform may be produced in any of the known ways, for example, by chemical vapour deposition of the appropriate doped silica materials within a tubular silica substrate. Firstly a cladding material, for example silica doped with  $B_2O_3$ , may be deposited  
15 followed by chemical vapour deposition of a core material for example silica or a silica doped differently from the core material, e.g. doped with germanium oxide ( $GeO_2$ ).



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Such techniques for producing a preform are known in themselves and it is known to produce an optical fibre by drawing from such a preform. To produce the spun fibre of the present invention, the preform may be

5 rotated during the drawing process. The rotational speed depends on the required spin rate and on the rate of drawing. Rotational speeds of up to 2000 r.p.m have in practice readily been obtained using a tachometer speed controlled d.c. motor with an accurately centred straight

10 preform. At a typical drawing speed of 0.5 m/sec., a spin rate of between 300 and 1500 r.p.m. is required for spin pitches of 10 cm to 2 cm. Much shorter spin pitches, e.g. 2 mm may readily be achieved at reduced pulling speeds. A spun fibre produced in this way

15 may be coated in a known way with a silicone rubber coating or other protective material.

In the following description, reference will be made to the accompanying drawings in which:-

Figure 1 illustrates diagrammatically one technique

20 for making an optical fibre; and

Figure 2 is a graphical diagram showing the relationship between birefringence and wavelength for two different fibres, one made in accordance with the present invention.



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A preform from which an optical fibre can be drawn is made in the known way by chemical vapour deposition of a cladding of doped silica, for example  $B_2O_3$  doped silica within a tube of pure silica, followed by deposition of a core, for example a germanium oxide doped silica, within the cladding. Such a technique is described for example in the communication by Norman, Payne, Adams and Smith on pages 309 to 311 of Electronics Letters, 24th May 1979 Vol. 15, No.11.

This preform is shown at 10 in Figure 1 and is attached to the shaft of a tachometer speed controlled d.c. motor 11 for rotation about its axis. The preform can be centred at its lower end by a guide, for example a spring-loaded diaphragm 12 mounted on an upper port of a pulling furnace 13 having a vertical axis. The fibre is drawn from the lower end of the preform in the known way. After fibre drawing has commenced, the motor is run up to the desired speed. A typical drawing speed of 0.5 m/sec. requires a spin rate of between 300 and 1500 r.p.m. for spin pitches of 10 cm to 2 cm. The fibre is drawn downwardly, as indicated diagrammatically at 15. The diameter of the drawn fibre is measured by measuring means 16 and the drawing speed is controlled automatically, by control means 17, in accordance with the measured diameter to



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maintain a constant diameter. The motor 11 is also controlled in accordance with the drawing speed so that a constant twist pitch is obtained despite any small variations in drawing speed caused by the automatic control of the diameter.

The drawn fibre may be coated with a silicone rubber coating using known techniques as indicated at 18. It has been found that the coating process and the diameter measurement and control system are not greatly affected by the rotation of the preform.

In the above-described embodiment, the preform is produced by chemical vapour deposition. It can however be made by a number of other known techniques, for example, VAD (vapour axial deposition), OVPO (outside vapour phase oxidation), rod and tube, stratified melt and updraw, ion exchange and the Phasil process. A particularly convenient technique is the double concentric-crucible method of manufacture in which an inner crucible contains the core glass and an outer concentric crucible contains the cladding glass, the fibre being drawn off through a common outlet at the bottom of the crucibles. In this case the double crucible assembly may be rotated but it may be preferred to rotate the tractor assembly.



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The effect of spinning on the birefringence properties of a number of fibres is illustrated in the Table below. In the first column of this table, various different fibres are indicated by a fibre number against which is marked the wavelength at which the measurement was made. Measurements of retardation and of rotation are given for four samples of spun fibre. For three of these fibres, measurements are also given for the fibre in the unspun condition. For fibre 319, results are given for two wavelengths.

It will be noted that, for the spun fibres, a reduction in linear retardance, compared with unspun fibres, which approaches two orders of magnitude has been obtained. The birefringence and circular rotation was measured using crossed polarisers and a Soleil compensator, with the fibre suspended vertically in order to reduce the effects of external stresses. Spinning the preform has been found to consistently reduce the birefringence to a level at or below the measurement limit and to introduce no circular birefringence.

The effect of fibre spinning on polarisation mode-dispersion was measured by determining the variation of fibre polarisation properties with wavelength. Raman generation in a single-mode fibre pumped with a Q-switched Nd:YAG laser was used as a tunable-wavelength source and





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the birefringence  $\Delta\beta$  and rotation in the test fibre measured as above. A typical result is shown in Figure 2 (upper curve) for an unspun fibre. The polarisation mode-dispersion  $\Delta\gamma = \frac{z}{c} \frac{d(\Delta\beta)}{dk}$  is estimated by fitting a curve to the data points and taking the derivative with respect to wavelength.

In the case of the spun fibre the birefringence and rotation was at the limits of detection and consequently only two points are shown on the lower curve in Figure 2.

10 The intrinsic polarisation mode-dispersion at a wavelength of  $1.2\mu\text{m}$  was calculated to be 4.6 ps/km for the unspun fibre and less than 0.02 ps/km for the spun fibre, this illustrating the large reduction possible with the spinning technique.

15 Analysis has shown that spun fibres are as sensitive as conventional low birefringent fibres to the Faraday effect and, furthermore, are not expected to exhibit significant polarisation variation with temperature. Low birefringence fibres are difficult to manufacture  
20 reproducibly and the spun fibre technique provides a simple alternative enabling reproducible fibres to be obtained which are suitable for use in a Faraday effect current transducer. In fibres for data transmission,



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the spinning ensures that the residual polarisation mode-dispersion is reduced to a negligible value and thus such fibres are attractive for long unrepeated links.

TABLE

FIBRE NUMBER		UNSPUN FIBRE	SPUN FIBRE	FIBRE SPIN PITCH
337 (633 nm.)	retardation rotation	450 %m. -50 %m.	2.3 %m. -0 %m.	5.0 cm.
302 (633 nm.)	retardation rotation	60 %m. 4.3 %m.	<1 %m. -0 %m.	1.0 cm.
333 (1064 nm.)	retardation rotation	- -	<2 %m. -0 %m.	3.9 cm.
319 (1064 nm.)	retardation rotation	232 %m. 1.1 %m.	<4 %m. 0.4 %m.	0.92 cm.
319 (1300 nm.)	retardation rotation	208 %m. 4 %m.	-4 %m. 0.6 %m.	0.92 cm.



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## CLAIMS:

1. An optical fibre of substantially torsion-free material with a rate of twist per unit length greater  
5 than the intrinsic birefringence.

2. An optical fibre as claimed in claim 1 wherein the rate of twist per unit length is at least ten times the intrinsic birefringence.  
10

3. A method of making an optical fibre comprising drawing the fibre from a heated preform whilst effecting continuous relative rotation between the preform and the drawn fibre.  
15

4. A method as claimed in claim 3 wherein the rate of rotation is such that the rate of twist per unit length of the drawn fibre is greater than the intrinsic birefringence.  
20

5. A method as claimed in claim 3 wherein the rate of rotation is such that the rate of twist per unit length is at least ten times the intrinsic birefringence.



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6. A method as claimed in any of claims 3 to 5 wherein, to effect the relative rotation, the preform is spun as the fibre is drawn.

5 7. A method as claimed in any of claims 3 to 6 wherein the spinning is at a rate to give a uniform number of turns per unit length.

8. A method as claimed in any of claims 3 to 7  
10 wherein the fibre is drawn at a substantially constant rate and the preform is spun at a substantially constant rate.

9. A method as claimed in any of claims 3 to 7  
15 wherein the rate of drawing is controlled to maintain the fibre diameter constant and wherein the rate of spin is controlled in accordance with the rate of drawing.

10. A method as claimed in any of claims 3 to 9  
20 wherein the preform is produced by chemical vapour deposition of glass materials within a tubular silica substrate.

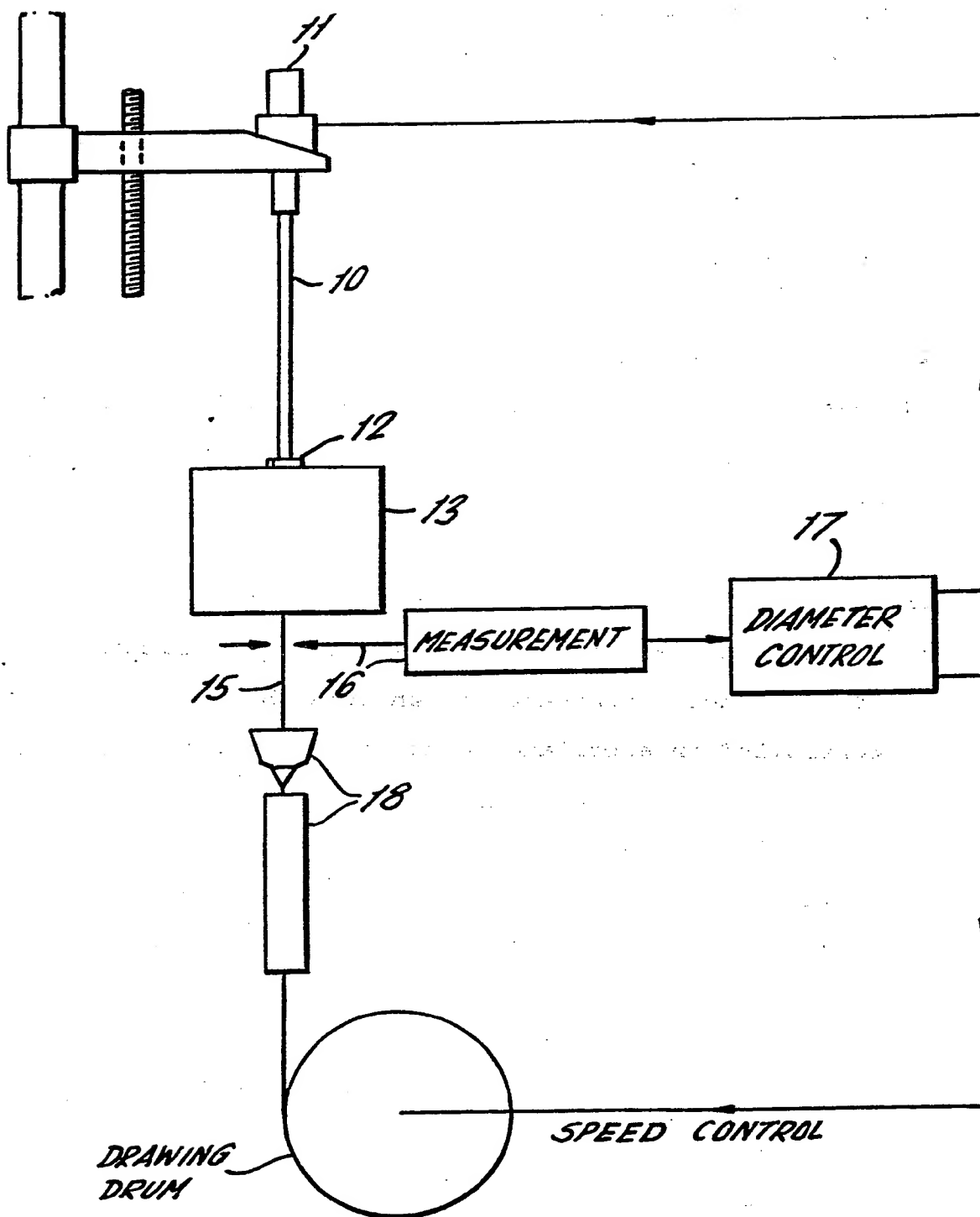
11. An optical fibre made by the method of  
25 any of claims 3 to 10.

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FIG. 1.

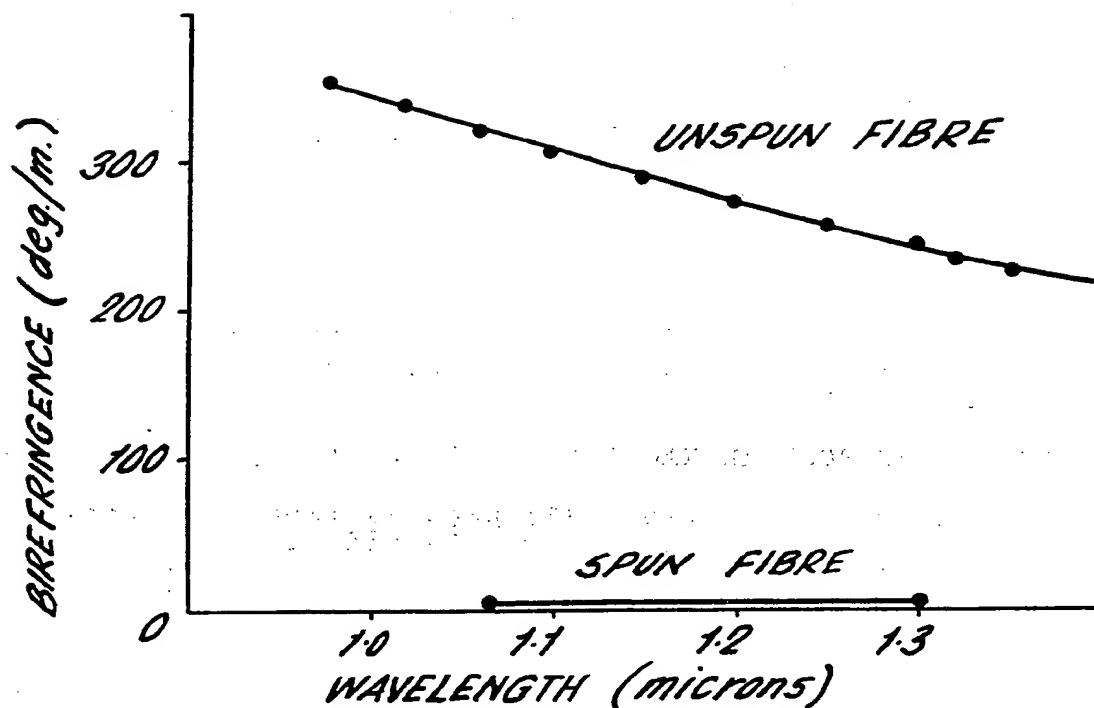


SUBSTITUTE SHEET



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FIG. 2.



SUBSTITUTE SHEET



# INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 82/00200

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC <sup>3</sup> : G 02 B 5/14; C 03 B 37/025		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>4</sup>		
Classification System	Classification Symbols	
IPC <sup>3</sup>	G 02 B 5/00; C 03 B 37/00	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>6</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>14</sup>		
Category *	Citation of Document, <sup>16</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No. <sup>18</sup>
X	Navy Technical Disclosure Bulletin, vol. 5, no. 12, issued December 1980 (Washington D.C., US) S.C. Rasleigh: "Fabrication of circularly birefringent single mode fibres", see figure; abstract; page 9, lines 8-11; page 8, lines 13-22; page 9, lines 4-8; see especially page 11, lines 8-18	1-6, 10-11
P, A	US, A, 4308045 (S.E. MILLER) 29 December 1981 see column 1, lines 35-64; figures 2-8; column 2, line 56 - column 3, line 68; claims 1, 5, 8, 9	1, 3, 6-8
A	FR, A, 2359087 (HITACHI LTD.) 17 February 1978 see page 1, lines 1-11; page 4, lines 6-32; claims 1, 2; figures 2a and 2b	8-10
A	DE, A1, 2855337 (WINTERHOFF, BARGMANN) 3 July 1980 see claims 1-3; page 1, line 1 - page 3,	2 ./. .
<p>* Special categories of cited documents: <sup>15</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"Δ" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search *	Date of Mailing of this International Search Report *	
13th September 1982	26th October 1982	
International Searching Authority *	Signature of Authorized Officer <sup>20</sup>	
EUROPEAN PATENT OFFICE	G.L.M. Kruydenberg	

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A	<p>line 4; figures; page 7, lines 11-16; page 8, lines 13-18</p> <p>2219 Applied Optics, vol. 17, no. 19, 1 October 1978, H. Schneider et al. "Low-birefringence single-mode optical fibers: preparation and polarization characteristics", see pages 3035-3037</p>	1,9
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V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE <sup>10</sup>

This International search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers..... because they relate to subject matter <sup>12</sup> not required to be searched by this Authority, namely:

2. ☐ Claim numbers....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out <sup>13</sup>, specifically:

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING <sup>11</sup>

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

- ☐ The additional search fees were accompanied by applicant's protest.  
☐ No protest accompanied the payment of additional search fees.